

Crocodilians and fisheries in the Philippines: revisiting Fittkau's hypothesis

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Abstract

Crocodilians have been assumed to influence aquatic primary productivity and fishery yield. However, strong empirical evidence to support such claims is lacking. The long-standing assumption first hypothesized by Fittkau (1970), is that local fisheries (secondary productivity) in areas inhabited by crocodilians would be expected to improve. We tested this hypothesis at two locations in the Philippines, inhabited by the Philippine Crocodile (*Crocodylus mindorensis*) in Paghungawan Marsh in Siargao Island Protected Landscape & Seascapes (SIPLAS), Jaboy, Pilar, Surigao Del Norte, and the Indo-Pacific Crocodile (*Crocodylus porosus*) in the Rio Tuba River, Bataraza, southern Palawan Island. Water chemistry parameters, with emphasis on nutrient (nitrate and phosphate) levels, were determined using standard protocols. Catch-per-Unit Effort (CPUE) of gillnets in sites with crocodiles was compared with corresponding control sites without crocodiles. CPUE was higher in areas inhabited by crocodiles, but appeared not to be directly influenced by nutrient levels. Increased fish catches in areas inhabited by crocodiles might be attributed to several factors, such as reduced fishing pressure due to the presence of crocodiles which discouraged the local fishermen to fish intensively. Overall, while fish catch was higher in areas inhabited by crocodiles, it is too early to attribute this to the nutrient output from crocodiles due to several confounding factors.

Keywords: estuarine, fish catch, freshwater, nutrient

Introduction

According to Fittkau (1970), the local inhabitants in the Amazon Basin reported a reduction in fish catch in the mid-20th century, which he postulated was caused by declines in the crocodilian populations in the lake-like lower reaches of rivers. He hypothesized that crocodilians (caimans) played a significant role in enriching the nutrient-poor water entering the mouth-lakes of the Amazon. This hypothesis has been used by conservationists to convince local communities to help conserve crocodilian species. However, Gorzula (1987) and Magnusson

(1990) pointed out that conservationists “rushed” to convince local communities of the importance of crocodilians to fisheries without enough supporting empirical evidence. More recently, Somaweera *et al.* (2020) exhaustively reviewed the literature on long-held assumptions of the ecological importance of crocodilians, including their roles in nutrient cycling, prey control, ecosystem modifications, among others. They concluded that the majority of the published literature on these topics, which stemmed from Fittkau (1970), was based largely on anecdotal and untested observations.

Two species of crocodiles occur in the Philippines: the widespread Indo-Pacific Crocodile or Estuarine Crocodile (*Crocodylus porosus* Schneider) (Fig. 1), and the endemic Philippine Crocodile (*Crocodylus mindorensis* Schmidt; Ross 2008) (Fig. 2). The former has a wide distribution, ranging from eastern India, through Southeast Asia, to Australia in the south and Pacific islands in the east (CSG, 1996). *Crocodylus porosus* is well-adapted to living in saline environments due to its well developed salt glands (Taplin and Grigg 1981), but is equally at home in freshwater habitats (Webb and Manolis 1989).

The Philippine Crocodile is a smaller species that is restricted to freshwater habitats but may also shelter in elevated cliff crevices and caves (Binaday *et al.* 2020). Although it had a

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Figure 1. Indo-Pacific Crocodile (*Crocodylus porosus*) in Palawan. (Photo by R. Manalo).

wider distribution in the past (Ross 2008, van Weerd *et al.* 2016), *C. mindorensis* populations currently only occur in northern Luzon Island, mainly in Isabela Province, and Ligawasan Marsh, in Mindanao Island (Ross 2008, van Weerd *et al.* 2016, Pomares *et al.* 2008). The Philippine Crocodile has been the subject of a reintroduction program, with the aim of increasing the size of the current wild populations and/or establishing populations in suitable habitats. Taking into account biological and social (community) variables, Paghungawan Marsh in Siargao Island, was assessed as a potential release site for *C. mindorensis* and 36 crocodiles were released there on 23 March, 2013 through a collaboration between Crocodylus Porosus Philippines, Inc. (CPPI), the local community (barangay Jaboy, Pilar, Surigao del Norte prov.), various Philippine government agencies (e.g., Department of Environment & Natural Resources, Philippine National Museum, local government units (LGUs), and the Silliman University-Angelo King Center for Research & Environmental Management (SUAKCREM; Manalo *et al.* 2016, Binaday *et al.* 2020).

Monitoring and research programs to assess the reintroduction program at Paghungawan Marsh were also undertaken by SUAKCREM and CPPI. Of particular interest was the hypothesis that crocodilians play a significant role in enhancing the nutrient regime of water bodies, which may enhance local fisheries as postulated by Fittkau (1970). The main objective of this paper is to assess the applicability of Fittkau's hypothesis in the Philippine setting. Specifically, we sought answers to the following questions: (1) Are fish catches generally higher in areas with crocodiles? and (2) Is there any evidence that aquatic primary productivity is higher in areas inhabited by crocodiles?



Figure 2. Philippine Crocodile (*Crocodylus mindorensis*) in the Paghungawan Marsh, Siargao Island. (Photo by P. Baltazar).

Methods

Description of Study Sites

Four study sites (Fig. 3) were identified, two on Siargao Island and two on Palawan Island, selected on the basis of similar environmental conditions and presence/absence of crocodiles.

Siargao Island Protected Landscape and Seascape (SIPLAS)

The two sampling sites were: Paghungawan Marsh in Barangay Jaboy (09.892897° N, 126.080508° E), Municipality of Pilar; and Sangay-Lilaw Marsh (09.991359° N, 126.069722° E) located 10.8 km north of Paghungawan Marsh in Barangay San Mateo, Municipality of Burgos, both in Surigao del Norte province. At both sites, the common vegetation is primarily swamp-associated species such as the cheesewood tree *Nauclea orientalis* (L.) Linn. (locally known as *bangkal*) and some herbaceous species like *Hypolytrum nemorum* (Vahl) Spreng. (CPPI, 2012). Inland freshwater areas in Siargao Island are not historically known to be inhabited by Philippine Crocodiles, but Paghungawan Marsh was considered owing to the presence of a group of introduced *C. mindorensis*. No crocodiles occur in Sangay-Lilaw Marsh. The sites were visited on 8–12 June, 2013 and 5–11 October, 2014. Both sites were accessed by foot from the nearest village.

Palawan Island

A population of Indo-Pacific Crocodile is present in the Rio Tuba Estuary (08.506373° N, 117.428132° E), located in Barangay Rio Tuba, Municipality of Bataraza. The river mouth extends at least 600 m inland, then gradually narrows over a

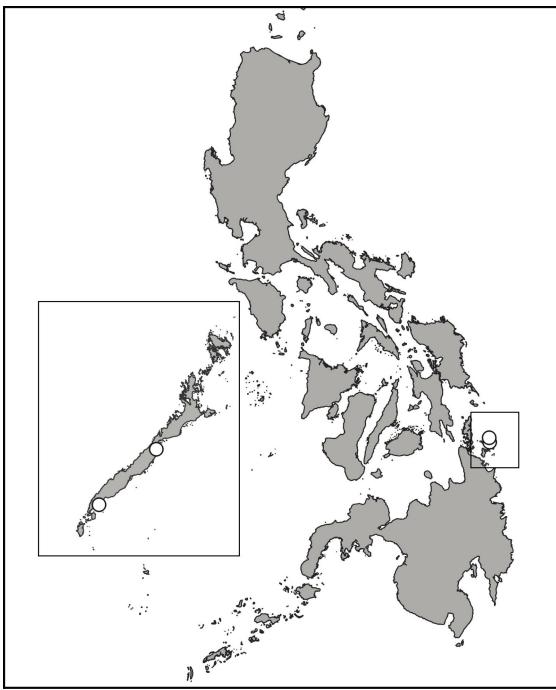


Figure 3. Location of the study sites.

further 400 m until it becomes just a small, non-navigable stream 6.29 km southwest of the mouth.

Crocodiles are not known to occur in Iwahig Estuary (09.736555° N, 118.696592° E), Barangay Iwahig, Puerto Princesa City. The mouth of the Iwahig River is about 80-390 m wide, i.e., narrower than that of Rio Tuba. The River is relatively deep near the mouth at about 3–5 m, then becomes shallower (0.5 m) some 10 km inland from the river mouth. The river banks of both sites supported dense growths of mangrove (mainly *Rhizophora* spp.), although patches were being illegally harvested for domestic use in Rio Tuba at the time of the study. Both sites were surveyed on 16–27 November, 2013 using motorized boats.

Fishery Assessment

Three gillnets, each measuring 15 m x 1.5 m and with a mesh size of 1.5 cm were used for sampling at all sites with the help of the local fishermen. At each site, deployment of gillnets was limited to one hour per gillnet during day time (11:00–12:00 in Siargao Island and 10:00–14:45 in Palawan Island). In Siargao Island, where the water levels were generally shallow, the gillnets were deployed in a semi-circle and fishes were driven towards the net by tow or three persons disturbing the water. Gillnetting in Paghungawan Marsh was done on 08 June, 2013 and 09 October, 2014.

In the estuarine sites (Palawan Island), gillnets were deployed (three gillnets at each site with one hour each, similar

to the procedures described above) towards high tide during daytime hours to account for possible marine species that enters the estuary at high tide. Deployment of gillnets in Iwahig River was done on 19 November, 2013 and in Rio Tuba on 23 November, 2013 during high tides. In Iwahig and Rio Tuba Rivers (depth 1–2 m), fishers disturbed the water by beating bamboo poles on the water surface for safety reasons. Fish catches were identified to species using available standard references such as FishBase (Froese and Pauly 2015), and the FAO Fish Identification Series by Carpenter and Niem (1999). Fish were measured and weighed and Catch-per-unit-effort (CPUE) calculated as kg/net/h. Fish lengths in the Siargao sites were also compared to show differences between sampling sites and dates.

One limitation of our study is the relatively small mesh size of gillnets and thus, larger fish samples may have evaded capture. CPUE estimates may be underestimated as a result.

Aquatic Primary Productivity

Prior to fish sampling, water samples were collected (see below) and the following *in situ* physico-chemical parameters measured at each site: sub-surface temperatures using field thermometers; pH using a pH meter (Hanna hi98108); salinity using a hand-held refractometer (Westover RHS-10ATC); and conductivity and total dissolved solids using a CyberScan Con 200 conductivity meter.

Three sets of sub-surface samples were collected for the following: 1) dissolved oxygen (DO) and biochemical oxygen demand (BOD) in BOD bottles; 2) gross primary productivity (GPP) and net primary productivity (NPP) in paired clear and wrapped (black plastic sheet) BOD bottles; and 3) 1-L water samples for total suspended solids (TSS), total hardness, methyl orange (MO) alkalinity, ammonia, nitrate and phosphate.

For DO and BOD, two sets of BOD bottles were dipped into the water and covered when full while still immersed in the water. At Day 0 (initial DO determination), oxygen was fixed by immediately treating the samples with $MnSO_4$ and alkaline KI and covering them with dark plastic bags. Winkler titration was done at the field working station. The water sample from the first bottle was subjected to Winkler titration to determine DO at Day 0. The second bottle was incubated (temperature not specified) for 5 d and the DO was then determined. BOD was then calculated as $DO_0 - DO_5$.

GPP and NPP were determined by the light and dark reactions (Chlores *et al.* 2013). Initial DO was determined as in DO determination. Paired BOD bottles, one transparent and the other wrapped in a black plastic bag, were suspended in the water about 30 cm from the surface, with each containing raw water collected at 30 cm depth. The samples were allowed to

incubate at this depth for 5 d.

Turbidity of the water samples was determined using a Merck Turbiquant 1500T. Total Hardness was determined using EDTA compleximetric titration. Fifty mL samples were titrated with standard EDTA. For the MO alkalinity, 50 mL samples were titrated with standard HCl solution. For TSS, a 1-L water sample was collected using polyvinyl containers and filtered through GF/C. The filtrate was collected and transported to the Silliman University (SU) Chemistry Laboratory for analysis of ammonia, nitrate and phosphate.

At the SU laboratory, ammonia, nitrate, and phosphate levels were determined following standard protocols (e.g., EPA 2012). For ammonia, water was treated with salicylate and hypochlorite which form an indophenols blue solution with ammonia. Absorbance of the colored product was measured at 640 nm using the Perkin Elmer Lambda 25 UV-vis spectrophotometer and concentrations of the samples were compared with standards at known concentrations. For the phosphate level, ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of orthophosphate-phosphorus to form an intensely colored antimony-phospho-molybdate complex. This complex was reduced to an intensely blue-colored complex by ascorbic acid. Absorbances of the colored solutions were monitored at 880 nm in the UV-vis spectrophotometer. Nitrate was reduced to nitrite via a cadmium-copper reductor column. Nitrite reacted with sulfanilamide to form a diazonium salt and coupling of the diazonium ion with N-(1-naphthyl)ethylenediamine to form a highly colored (red-purple) azo compound. Absorbances were read at 540 nm.

Results and Discussion

Impact of crocodiles on fish length and CPUE in Paghungawan Marsh

This is the first attempt to determine whether crocodiles contribute to the overall production of aquatic ecosystems in a Philippine setting, thereby resulting in higher yields for local fisheries. Although various researchers (e.g., Balbas 2012; van der Ploeg 2012) in the Philippines have reported that local fishers often fish in areas inhabited by crocodiles, the documentation of catch composition, CPUE and other fishery parameters is lacking.

It should be noted that it was the local community's initiative to legislate a Barangay Ordinance No. 01-2013 to completely ban gillnetting and other poisonous substance in Paghungawan Marsh to ensure the survival of the remaining *C. mindorensis*. This was in support to the issued SIPLAS-Protected Area Management Board (PAMB) Resolution No.

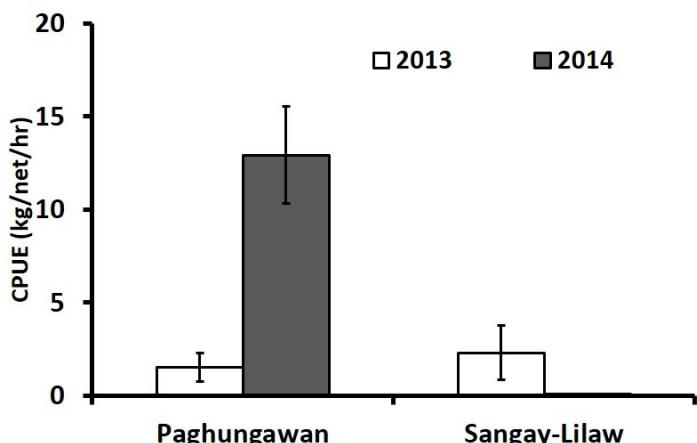


Figure 4. Mean gillnet CPUE data before and a year after fishing closure in Paghungawan Marsh compared to the control site. N= 3 net-hours per sampling. Error bars indicate Standard Error (SE).

2013-23, which classified Paghungawan Marsh as a Strict Protection Zone. Deputized wildlife enforcement officers who are members of the People's Organization Jaboy Ecotourism and Conservation Organization, Inc. (JECO) have actively participated in the confiscation of gillnets and dismantling of stationary hook and line installed by fishers from adjacent communities.

From comparing before and after mean gillnet CPUE in Paghungawan Marsh (expressed as mean \pm standard error) data (2013, prior to fishing closure vs. 2014, about a year after implementation), CPUE increased from 1.53 ± 0.77 kg (S.E.) to 12.92 ± 2.6 kg (t-test p-value=0.013668). In contrast, in Sangay-Lilaw Marsh, where fishing was uncontrolled, gillnet CPUE decreased from 2.29 ± 1.46 kg in 2013 to 0.08 ± 0.003 kg in 2014 (Fig. 4).

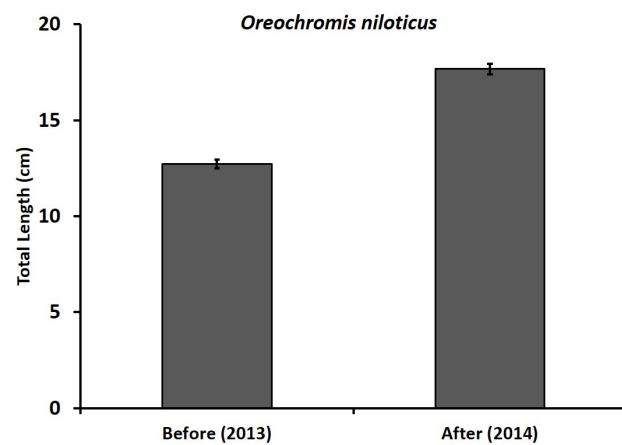


Figure 5. Mean length data of *Oreochromis niloticus* in Paghungawan Marsh in June 2013 (N=82) and October 2014 (N=177). t-test indicates significant difference between the means. Error bars indicate standard error (SE).

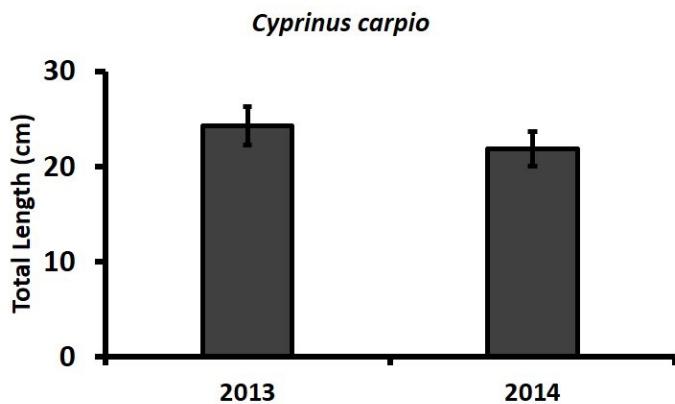


Figure 6. Mean length of *Cyprinus carpio* in Paghungawan Marsh between June 2013 (N=19) and October 2014 (N=12). t-test indicates no significant difference between the means. Error bars indicate standard error (SE).

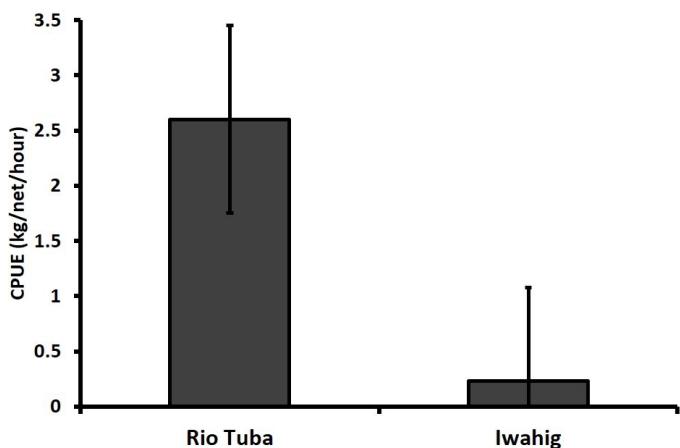


Figure 7. Gillnet CPUE in Rio Tuba compared with Iwahig Estuary in November 2013. N= 3 net-hours per site. Error bars indicate standard error (SE).

The increased CPUE in Paghungawan Marsh due to the gillnet ban was not surprising. As fish are allowed to grow to a certain size by reducing mortality (e.g., inside marine protected areas), weight (biomass) of fish also increased as a function of length (Alcala and Russ 1990, Alcala 2001). Total length (measured to the nearest cm) of Nile Tilapia [*Oreochromis niloticus* (Linn.)] (which is also targeted by the local fishers), also increased from 12.73 ± 0.22 cm in 2013 (N=82) to 17.67 ± 0.28 cm in 2014 (N=177), with Welch's two sample t-test results indicating that the difference between the two means is significant ($p\text{-value} < 0.001$; Fig. 5). Total lengths of another targeted fish (*Cyprinus carpio* Linn.) remained stable (24 mm TL to 22 mm TL) between 2013 and 2014 (t-test, $p\text{-value} 0.42 > 0.05$; Fig. 6).

Crocodiles and local fisheries in Palawan

Mean CPUE was 0.23 ± 0.16 (SE) kg/net/h in Iwahig (Fig. 7) and 2.6 ± 0.85 kg/net/h in Rio Tuba. Most of the fish caught in Rio Tuba Estuary were target or food fishes, such as rabbitfish (Siganidae), jacks (Carangidae), and emperors (Lethrinidae), whereas ponyfish (Leiognathidae) predominated in the Iwahig River Estuary. The increased fish catch in Rio Tuba might be attributed to several factors, such as low fishing pressure, as the presence of *C. porosus* in the river discouraged intensive fishing by local fishermen.

Crocodiles and aquatic productivity

The physico-chemical data from all sites are summarized in Table 1. As shown in Fig. 8a, in Paghungawan Marsh, the mean nitrate levels increased from 8.36 mmol/L in 2013 to 13.14 mmol/L in 2014. Likewise, in Sangay-Lilaw Marsh, an increase from 9.8 mmol/L (2013) to 13.47 mmol/L (2014) was also observed. However, between the two locations, nitrate levels did not differ significantly. Phosphate levels showed high variation between sampling locations but showed a declining trend from 0.72 mmol/L (2013) to 0.33 mmol/L in Paghungawan Marsh while a similar trend was observed in Sangay-Lilaw Marsh, from 0.6 mmol/L (2013) to 0.18 mmol/L

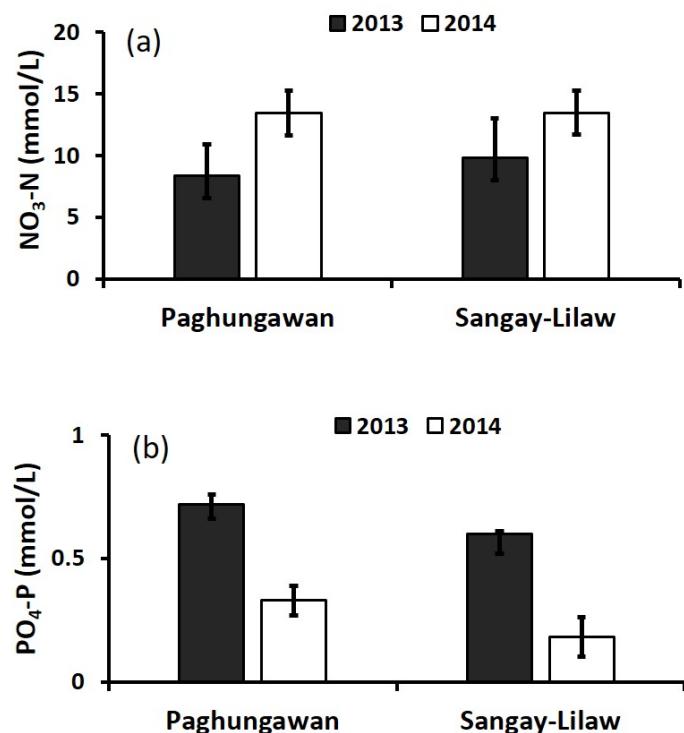


Figure 8. Nitrate (a) and phosphate (b) levels in Paghungawan Marsh compared to Sangay-Lilaw Marsh between June 2013 (N=6 per site) and October 2014 (N=6 per site).

Table 1. Physico-chemical parameters of the study sites.

Parameters	Siargao Island								Palawan			
	Paghungawan				Sangay-Lilaw				Iwahig		Rio Tuba	
	2013		2014		2013		2014		Mean	s.e.	Mean	s.e.
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	n/a	n/a	n/a	n/a
temperature, °C	32.78	1.00	31.67	0.33	31.10	0.10	34.00	0.00	n/a	n/a	n/a	n/a
pH	8.46	0.05	7.47	0.18	7.40	0.10	8.30	0.06	7.90	0.03	7.50	0.07
Salinity, ppt	0.00		0.00	0.00	0.00		0.00	0.00	14.00	0.00	27.00	1.15
Conductivity, mS	259.83	50.57	146.00	7.00	184.50	4.30	443.67	12.17	25.50	0.50	44.30	1.36
Turbidity, NTU	148.03	27.80	75.43	2.77	8.80	2.30	3.43	0.69	6.26	0.60	3.42	1.39
TSS, mg/L	135.98	23.06	64.03	8.70	4.88	0.90	5.63	0.29	12.70	0.35	14.80	0.21
TDS, mg/L	150.95	29.46	84.60	4.10	107.02	2.50	261.33	6.39	14.80	0.30	25.70	0.78
Total Hardness, mg CaCO ₃ /L	98.88	3.16	82.90	0.89	145.80	32.40	207.47	1.68	3034.77	54.00	6111.13	162.65
MO Alkalinity, mg CaCO ₃ /L	92.42	2.10	87.73	0.97	133.80	30.10	208.87	1.78	153.80	1.50	176.17	4.61
DO, mg O ₂ /L	6.81	0.52	6.51	0.10	6.84	1.00	5.64	0.11	3.90	3.89	2.09	0.08
BOD, mg O ₂ /L	6.17	0.54	n/a	n/a	1.96	0.10	1.69	0.14	0.46	0.10	0.27	0.22
GPP, mg C/m ³ /hr	12.70	1.85	40.19	21.64	3.82	0.80	5.25	0.25	2.73	0.40	1.61	0.76
NPP, mg C/m ³ /hr	-10.24	2.88	<1.86	<.81	4.07	0.60	<.81		3.3	0.5	<2.46	
NH ₃ -N, mmol/L												
NO ₃ -N, mmol/L	8.36	2.54	13.47	1.79	9.85	3.20	13.47	1.79	8.04	0.8	5.48	0.67
PO ₄ -P, mmol/L	0.72	0.04	0.33	0.06	0.61	0.01	0.18	0.08	2.18	0.70	0.70	0.01

(2014) mmol/L, probably due to dilution from increased rainfall coinciding with the southwest monsoon during the sampling in 2014. In the more than one year since the crocodiles were released in Paghungawan Marsh, the aquatic primary production also increased. However, this might be attributed to other factors as well, including higher nutrient input from the decomposing vegetation in the adjacent forest (Webster and Benfield 1986) and possibly from upstream sources, such as agricultural runoff (Briones 2005). Although it can be assumed that at this stage the excreta of the small, recently introduced Philippine Crocodiles may have contributed only a small amount of nutrients to the water, it is possible that they can help enhance the nutrient level in the water column as they scour the substratum (including attached algae or periphyton) when foraging.

In the estuarine sites, Iwahig River Estuary had higher values of both nitrate (8.04 ± 0.75 mmol/L) and phosphate (2.18 ± 0.69 mmol/L) compared to those in Rio Tuba River Estuary with nitrate and phosphate levels of 5.48 ± 0.67 mmol/L and 0.67 ± 0.013 mmol/L, respectively (Figs. 9a, b).

Such differences in both nitrate and phosphate levels might be influenced by other sources such as from nearby farms and households (< 1 km away), surrounding vegetation and

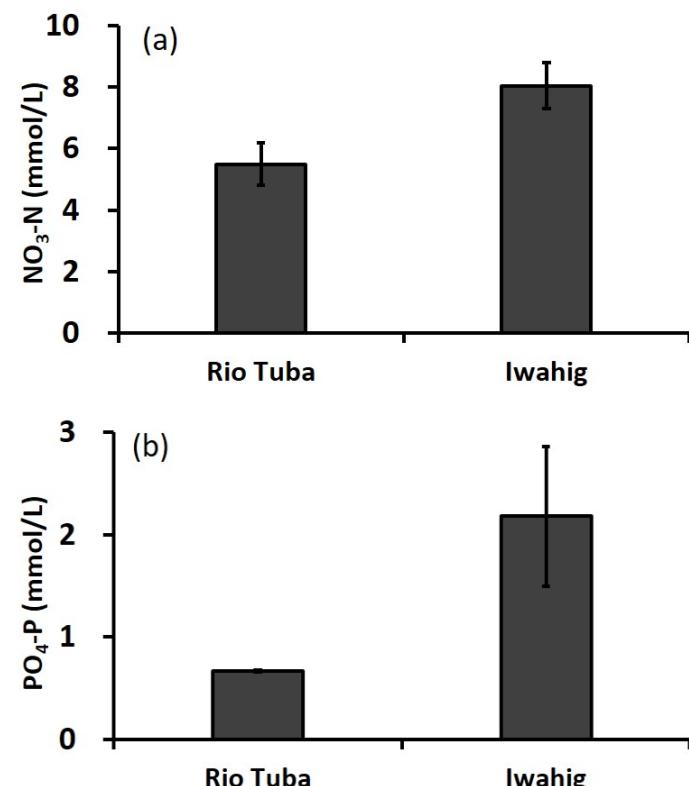


Figure 9. Nitrate (a) and phosphate (b) levels in Rio Tuba (N=3) and Iwahig (N=3) in November 2013.

erosion, and may not be directly linked to the presence or absence of crocodiles.

Although there seems to be a long standing assumptions among ecologists that crocodiles serve as keystone species (e.g., Ashton 2010), a recent review by Somaweera *et al.* (2020) pointed out that little empirical evidence exists for the claim that crocodiles improve fish catches. The present study appears to be the first major attempt to quantify fish catches in areas inhabited by the two species of crocodiles in the Philippines. At this stage, however, these data can be used only to compare between the two Palawan sites (spatial), whereas temporal comparisons can be derived later as fish catch data accumulate over time.

It has long been assumed that crocodilian metabolic wastes are rich in phosphorus and nitrogen (Sudha and Vasudivan 2009, 2012). Lawrence and Loveridge (1988) demonstrated that a 4-kg and 10-kg Nile Crocodile (*C. niloticus* Laurenti) excreted 49–63% respectively of the nitrogen contained in their food and they also showed that the majority of the nitrogen was excreted in the form of uric acid (38–42%) and only a small amount is ammonia (2.3–2.7%). However, their study may have been complicated by dehydration as shown by decreasing weights of the crocodiles in the experiment. Nonetheless, it is noteworthy that the animals retained 37–51% of the nitrogen consumed. It should be noted that all crocodilians studied to date mainly excrete waste nitrogen as ammonia, with much smaller quantities as urea and uric acid (urates; Khalil and Haggag, 1958). Of the nitrogen excreted by crocodilians living in fresh water, little is of the insoluble form. Studies carried out with *C. porosus* indicated that only about 1% of the excreted nitrogen was in the solid fraction (mainly urate salts) - most nitrogen excreted (about 90%) was in the form of ammonium bicarbonate (NH_4CO_3 ; see also Schmidt-Nielsen and Skadhauge, 1967). Australian researchers estimated that 40 maximally-fed adult *C. porosus*, with a total biomass of around 10,000 kg and food intake of some 5,000 kg in one year, produced 77 kg of waste nitrogen and 8 kg of waste phosphorus (C. Manolis, *pers. comm*), suggesting that most of the wastes had dissipated in the air as ammonia. Applying these estimates to Paghungawan Marsh, where 36 *C. mindorensis* were released, with a total biomass of 47.33 kg at the time of release in 2013, consumed 5% of their bodyweight per week (this is about 20% in farmed individuals), they would be consuming around 114 kg of food in a year. Based on mean annual weight (5.2 kg) gains of re-captured individuals, the accumulated biomass would be around 234 kg in a year, and annual production of nitrogen would be around 1.6 kg and phosphorus of 0.16 kg. Over a year, these amounts of nutrients would probably be minimal relative to contributions from other sources.

Moreover, studies such as this may be confounded by the

fact that it is almost impossible to find an aquatic ecosystem in developing countries like the Philippines without any human influence, including organic pollution (Tamayo-Zafaralla *et al.* 2002, Islam and Tanaka 2004).

Overall, this study supports the notion that crocodilians may have very little influence on the nutrient regime of the water and subsequently on aquatic productivity as pointed out by Somaweera *et al.* (2020). In this regard, it is noteworthy to refer to the case of Mary River, in the Northern Territory, Australia, which has the highest density (and biomass) of saltwater crocodiles in Australia (Fukuda *et al.* 2011), and is one of the best rivers for fishing barramundi *Lates calcarifer* (Bloch) (Northern Territory Government, 2018). There were no saltwater crocodiles in the Mary River 48 years ago, and even then, it was one of the best rivers for barramundi. Fish do not form a major part of the diet of these crocodiles. The River is simply very productive for fish and other wildlife regardless of whether there are crocodiles present or not. On the other hand, the adjacent Adelaide River has a good population of saltwater crocodiles but fishing there remain very poor, even when there were few/no crocodiles there in the 1970s (C. Manolis, *pers. comm.*).

Conclusion and Recommendations

Gillnet CPUE values in areas inhabited by crocodiles were significantly higher than those in areas where they were absent. This provides a modicum of support for the Fittkau (1970) hypothesis. However, aquatic primary production (gross and net production) do not conform to the observed CPUE trend (higher CPUE in areas inhabited by crocodiles), and could be influenced by other factors, such as availability of other sources of nutrients like mangrove detritus. More research work is required before a definite conclusion can be made.

It is recommended that the study be extended into a long-term monitoring of both nutrient level of the water and fish catch to cover possible seasonal variations.

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